Chapter 11

Drying Technology

Drying Technology

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1. BASICS OF DRYING

Drying means in general the removal of water from a material. This might be a mechanical or a thermal "dewatering".

Materials to be dried in the cement industry are normally thermally dewatered, that means the removal of moisture by evaporation under utilization of various types of hot gases.

Types of moisture are:

♦ Surface moisture
  water film on particle surface causing agglomerations of fine particles

♦ **Outer Moisture** (provokes handling problems)

  • cavity moisture
    droplets captured in voids between fine particles

  • capillary moisture
    water drawn in thin gaps between surfaces leads to adhesion and agglomerations of particles

♦ **Inner moisture** (no influence on handling)

  • pore moisturewater
    contained in pores

  • inherent moisturenatural moisture
    inhibited in solid materials

The drying process is mainly influenced by the

♦ characteristics of material

♦ percentage of moisture

♦ type of moisture

♦ particle size of material

♦ time of exposure to heat

♦ drying system

When drying a material, first the surface then the outer and at last the inner moisture is evaporated due to the heat transfer and moisture diffusion. The outer and surface moisture can evaporate easily. The inner moisture has to diffuse first to the particle surface, from where it can be evaporated. This diffusion of moisture is facilitated by heating up the particle.

The water evaporation rate of a moist material increases with higher hot gas temperature and is different for each material.

The residence time during which a particle is exposed to drying gases as well as the particle sizes are of utmost importance for a sufficient drying.

Figure 1: Moisture and drying speed
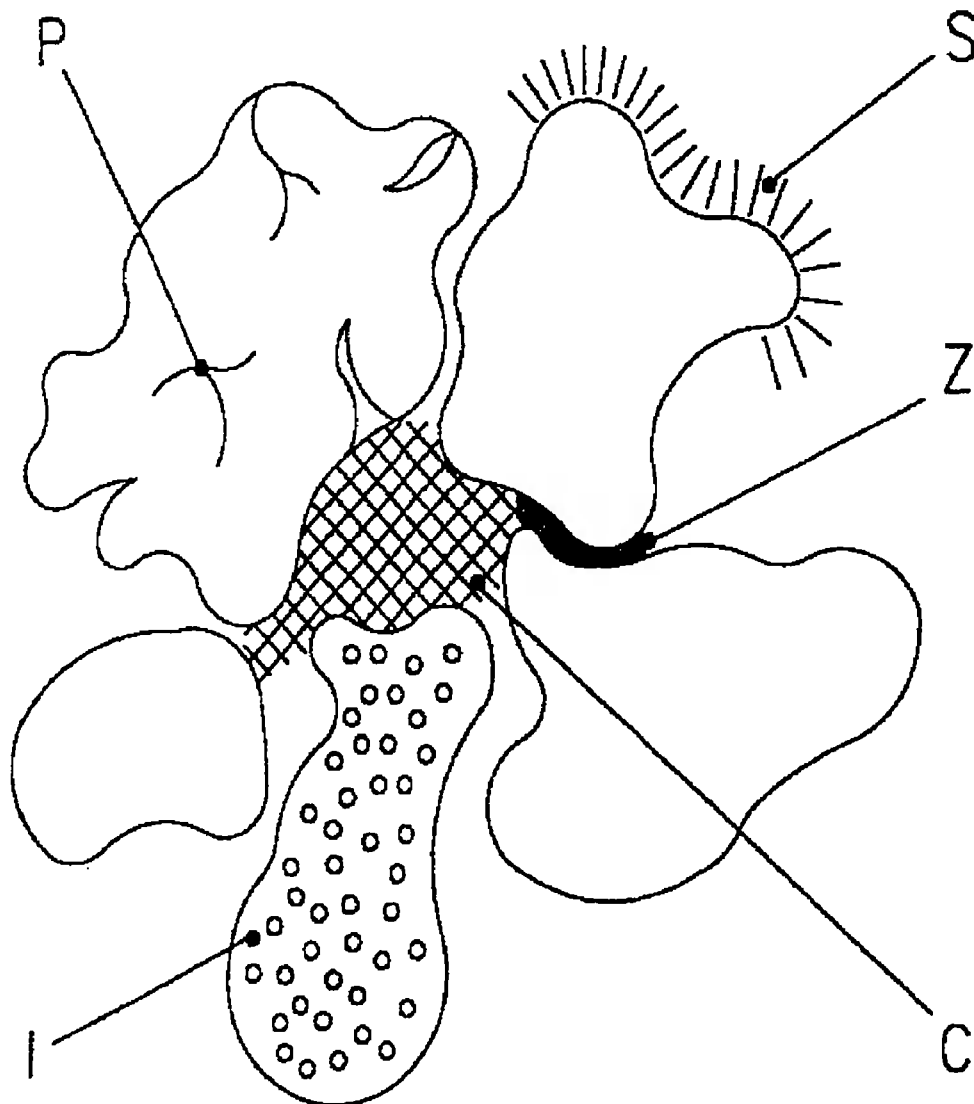
C   cavity moisture ⎫
                    ⎬ poor handling
Z   capillary moisture ⎭

S   surface moisture ⎫
                     ⎬ good handling
P   pore moisture ⎭

I   inherent moisture

moisture

surface S

outer C,Z

inner P,I

drying time
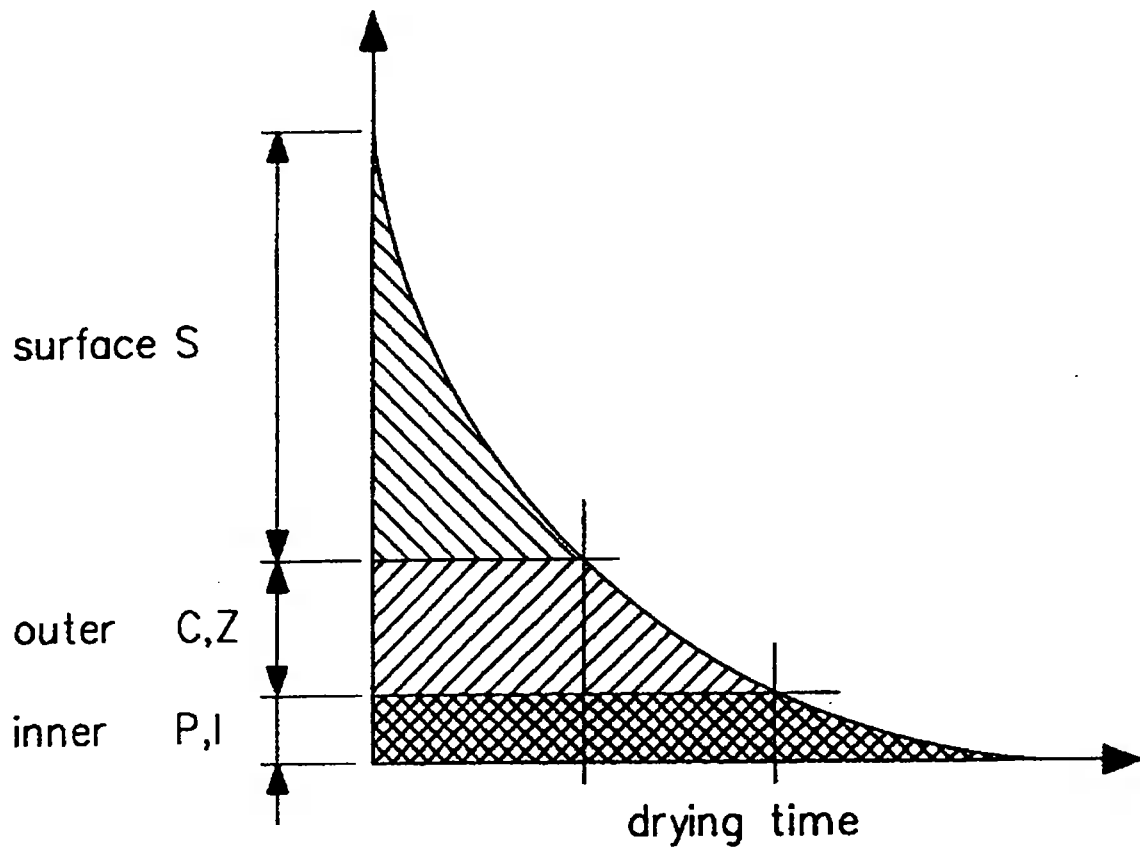
2. ANALYSIS AND CALCULATION

Remember: The values of moisture content are always indicated on wet basis and weight percent. This means that the weight of the wet material is always 100 %. This rule corresponds to the analysing method in the laboratory.

In thermal drying processes, the heat is transferred mainly by convection from the gas to the material and moisture.

Major possible heat sources:

♦ kiln exhaust gases   < 350 [°C]   (depending on system)

♦ clinker cooler exhaust air < 350 [°C]   (depending on system)

♦ hot gases (hot gas generator)   < 1300 [°C]

♦ grinding heat (electrical/mechanical energy)

♦ clinker heat (for cement grinding)

The necessary energy of a drying gas is expressed by

$$Q = V \cdot t \cdot cp$$

Q   =   required energy   [kJ/h]

V   =   gas flow rate   [Nm^3/h]

t   =   gas temperature   [°C]

cp   =   spec. gas heat   [kJ/Nm$^3 \cdot$ °C]

and has to be found through a heat balance.

The residual moisture is mainly a function of the exhaust gas temperature and the dry product temperature after the drying process. For raw material drying, the residual moisture is generally < 1 [%] H_2O and for cement close to zero.

Some types of coal are only dried to the level of the hygroscopic moisture, as the coal will reabsorb moisture to the equilibrium point. The hygroscopic moisture has no negative effect on the flowability and handling ability of the coal.

Often, drying of material is done in connection with a grinding process, so called drying/grinding, e.g. raw mill, coal mill, cement mill. General drying is done in drying equipments (dryers).

Special attention has to be paid to the dedusting equipment of drying installations. Drying exhaust temperatures have preferably to be kept about 30 [°C] above the dew point temperature of the exhaust gas to avoid condensation of the moisture in contact with ambient air or cold spots of the equipment. Sometimes filters and ducts need insulations.

Problems may arise with the handling of material which is partially dried and the dedusting equipment. Partially dried and warm material is difficult to handle and develops vapors which often clog the filterbags.

"HOLDERBANK"

Figure 2: Analysis and calculation

Analysis :

Moisture content ⟶ Wet basis (weight %)
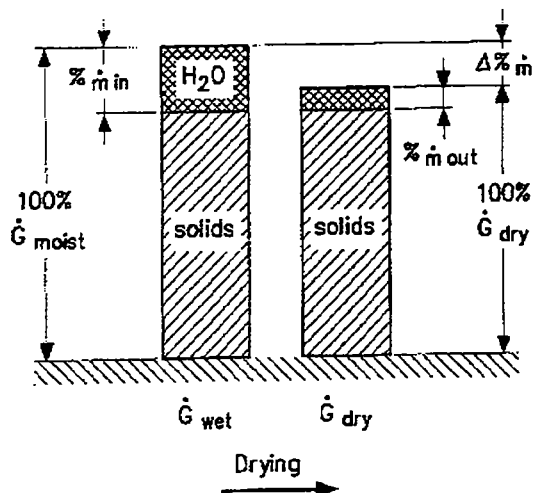
$\dot{G}_{wet}$ moist material (feed)   (t/h)
$\dot{G}_{dry}$ dryed material (product)   (t/h)
$\%\dot{m}_{in}$ initial moisture   (%)
$\%\dot{m}_{out}$ residual moisture   (%)
$\dot{m}$ evaporated moisture   (t/h)

$$\text{Product } \dot{G}_{dry} = \dot{G}_{wet} \cdot \frac{100 - \%\dot{m}_{in}}{100 - \%\dot{m}_{out}} \quad (t/h)$$

$$\text{Evaporated moisture } \dot{m} = \dot{G}_{wet} \cdot \frac{\%\dot{m}_{in} - \%\dot{m}_{out}}{100 - \%\dot{m}_{out}} \quad (t/h)$$

3. DRYERS

3.1 Drum dryers

Design

The drum or rotary dryer consists of an inclined steel tube on two tyres driven by a girth gear drive. The dryer volume is essential for the amount of water to be evaporated. Usually the L/D ratio is kept < 8 [-].

Drying

The heat exchange in a drum dryer depends mainly on:

♦ drum speed

♦ inlet gas temperature

♦ gas speed within the drum

♦ type, size and surface of internal fittings

Drum dryers are specially suited for moist and sticky material (clay components) and allow a larger material feed size than other dryers.

♦ Parallel flow
   Material and gas flow in parallel from the inlet to the discharge. Moist feed material is already exposed to the hot gas at the dryer inlet. This prevents from clogging the inlet and improves the material flow through the dryer.
   High hot gas inlet temperatures are possible and advantageous (high temperature difference between moist material and hot gas) for a more efficient heat exchange. Parallel flow operation is always preferred.

♦ Counter flow
   The hot gases enter at the drum discharge, where the material moisture is low. A main disadvantage of this principle is that the gases at already low temperatures enter in contact with the moist feed material. An increase in hot gas temperature leads mainly to unnecessary heating-up of the discharge material. On the other hand, the dust emission is relatively low. Counterflow operation is generally not recommended.

Features

♦ retention time depends on:

   • dryer rotating speed   2 - 5 [min^{-1}]

   • dryer inclination   3 - 6 [°]

   • internal fittings

   • gas speed   < 6 [m/s]

♦ dust load   < 150 [g/m^3]   in exhaust

♦ pressure drop   2 - 5 [mbar]   accross drum

♦ exhaust gas temperature   100 - 120 [°C]   Recommende

♦ specific electrical energy consumption   ~ 3 [kWh/t]   for drum, transport and fan

Figure 3: Drum (rotary) Dryer

Feed size	(mm)	200–300
Drying capacity	(%H_2O)	< 25
Spec. load	(kg $H_2O/m^3 \cdot h$)	< 150 depending on internal fittings
Temperature max.	(°C)	< 1200

3.2   Dispersion Dryer

Design

Dispersion dryers are comparable with a drying compartment of a tube mill. The drums are short (L/D ~ 2.5 [-]) and contain lifter plates for the material dispersion across the entire drum length.

The inlet is generally fitted with a trunnion bearing and the support at the discharge end is combined with the central drive shaft.

A retention ring at the outlet retains the material to a certain level. As the dryer drum is horizontally without inclination, the material movement towards the outlet is strongly influenced by the material flowability and the gas speed.

Drying

Material and hot gases are introduced through the trunnion bearing into the drum. Radial openings at the outlet provide the material discharge and the exhaust gases leave the dryer through the discharge hood to a dust collecting facility.

The hot gas temperature at the inlet is limited by the admissible temperature for the trunnion bearing.

The lifter plates disperse the material over the dryer cross section for a good contact with the hot gases.

The evaporation rate depends very much on:

♦   gas inlet temperature

♦   material dispersion
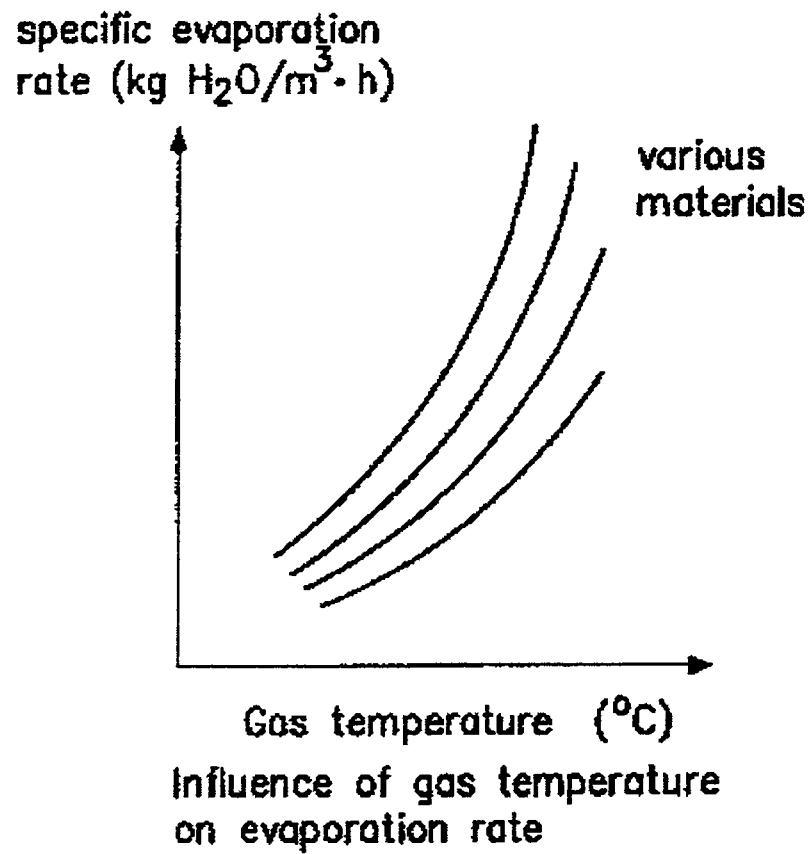
♦   material granulometry

♦   retention time

Features

♦   rotating speed ~70 [%] or critical speed, which is almost the same as for a tube mills

♦   higher material filling degrees than drum dryers, up to 15 [%] according to the retention ring at the outlet

♦ gas speeds	< 3 - 4 [m/s]	in drum
♦ dust load	< 300 [g/m³]	exhaust gas
♦ pressure loss	< 30 [mbar]	depends also on internal fittings, inlet, outlet arrangement
♦ spec. energy consumption	< 1 [kWh/t]	drum
	< 3.5 [kWh/t]	system

Figure 4: Dispersion Dryer

System

- - - - - ▶ hot gas

─────▶ material
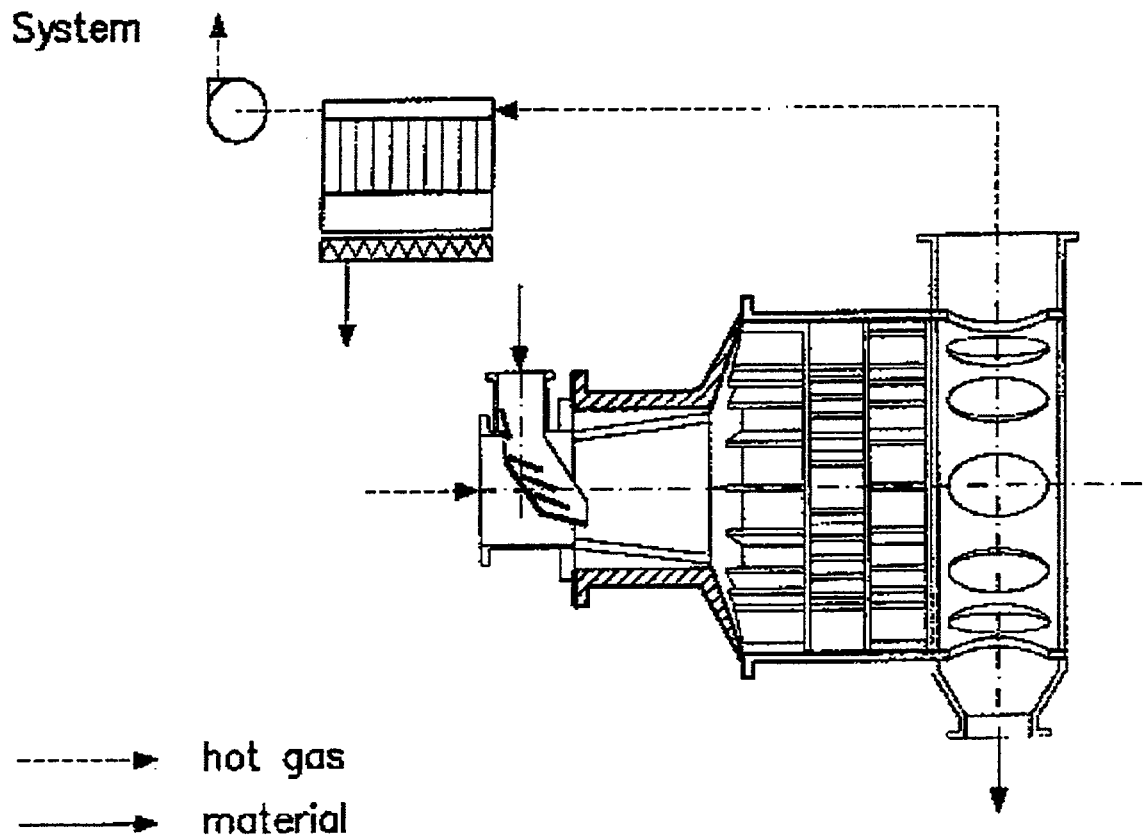
Feed size	(mm)	20–30
Drying capacity	($\%H_2O$)	< 15
Spec. load	($kg\ H_2O/m^3 \cdot h$)	< 200
Temperature max.	(°C)	< 850

specific evaporation
rate (kg $H_2O/m^3 \cdot h$)

various
materials

Gas temperature (°C)

Influence of gas temperature
on evaporation rate

3.3   Rapid Dryer

Design

The rapid dryer is stationary and consists of an air-tight closed casing. The lower part is fitted with one or two rotating shafts which are fitted with paddles. The paddles throw the material up and disperse it in the gas stream.

The material transport is based on the paddle action and the gas flow through the dryer.

As the casing is stationary, it can very well be sealed with an inlet and outlet airlock.

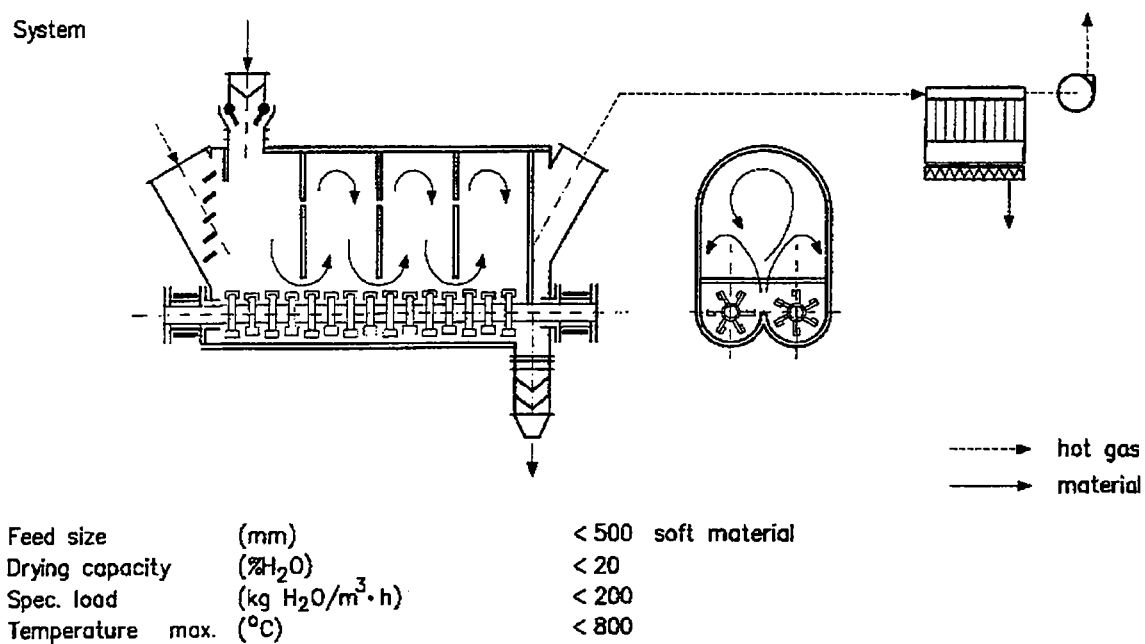The casing inside is lined with wear resistant plates for abrasive materials.

Drying

Rapid dryers are operated in parallel flow mode. High hot gas temperature may be used if necessary, which leads to sufficient casing wall temperature to prevent build-ups in case of moist feed components.

The mechanically forced dispersion of material in the gas stream enables an intense heat transfer efficiency and therefore a quick water evaporation.

Features

♦ air speeds in dryer   < 1.0 [m/s]

♦ suppliers indicate that slurries with extreme high moisture content can easily be dried (attention to dew point and filter operation!)

♦ one-shaft dryers are available up to an evaporation rate of 2'500 [kg H_2O/h]

♦ the largest dryers available can dry up to 25'000 [kg H_2O/h]

♦ this dryer occupies little space

♦ special attention has to be paid to wear on the paddles when processing abrasive materials (slag etc.)

♦ the energy consumption of rapid dryers is in general higher than for drum dryers due to the mechanical dispersing by the paddles.

Figure 5: Rapid Dryer

System

--------▶ hot gas
———▶ material

Feed size	(mm)	< 500 soft material
Drying capacity	(%H$_2$O)	< 20
Spec. load	(kg H$_2$O/m^3·h)	< 200
Temperature max.	(°C)	< 800

3.4   Dryer-Crusher

Design

As the name reveals, the dryer-crusher is suited for the comminution and the simultaneous drying of soft and low abrasive materials. Moist feed materials pass through an impact or a hammer rotor and are most of the time extracted by the proper drying gases. The discharged, ground or partly ground and dried material may pass a classifier (static or dynamic) for separation of already fine enough particles. The return material from the separator reenters the crusher, the fines are swept to a dust collector.

Dryer-crushers are used in many different arrangements and set-ups according to the needs and possibilities.

Drying

The drying process takes place in the crusher and during the subsequent air transport. The comminution of the feed material improves tremendously the drying effect, as smaller particles provide much better evaporation of moisture.

The hot gases through the crusher rotor avoid clogging and blockage of the casing. The hot gas temperature is limited by the heat based stresses and dilatation of the rotor parts.

Crushers with gravity discharge have a much lower drying efficiency than the air-swept types. The effect is a result of smaller dryer volume and thus lower retention time.

Features

♦ circumferential rotor speed 25 - 35 [m/s]

♦ suited for partial predrying ahead of a mill

♦ single and double rotor crushers available

♦ spec. energy consumption of crusher depends on:
  • material hardness
  • particle size reduction ratio
  • produced fineness
  • feed moisture

Figure 6: Dryer-crusher (with separator)

System


```
-------►  hot gas
— ---►  material
```
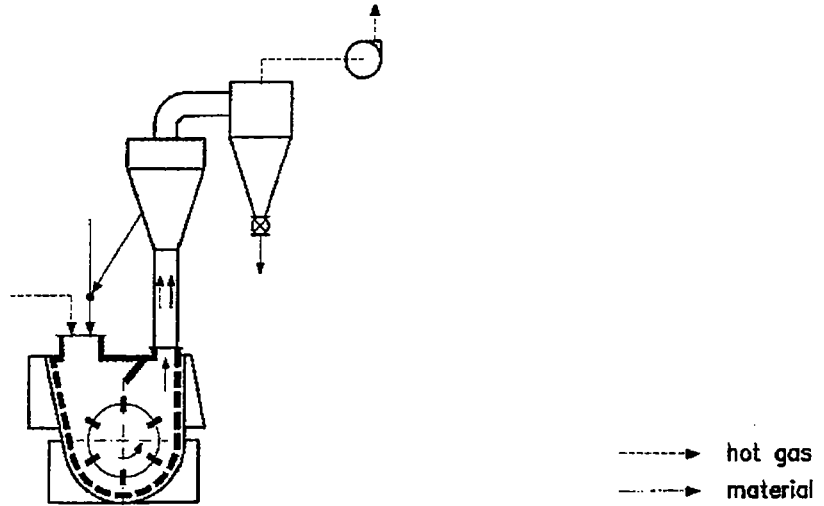
Feed size	(mm)	< 150	(depends on crusher size)
Drying capacity	($\%H_2O$)	< 25	(air-swept with flash dryer)
Spec. load	(kg $H_2O/m^3 \cdot h$)	< 500	(air-swept with flash dryer)
Temperature max.	($^\circ$C)	< 800	

3.5   Flash dryer

Design

Flash dryers have a wide field of applications. They usually are used ahead or in connection with an additional equipment (crusher, mill separator etc.).

Hot gases are drawn through a vertical duct with a fan, while moist material is fed to the upward flowing gas stream. Often a disagglomerator is installed ahead of the flash dryer to ensure a fine enough granulometry. The finer, dried material is collected in a dust collector where the large particles fall out of the dryer through an airlock.

L/D-ratios reach as far as 8 - 20 [-] according to application and fineness of material.

Drying

Drying takes place during the pneumatical transport with the drying gases. The vertical gas speed has to be superior to the terminal velocity of the particles to be lifted-up. The heat transfer from the gases to the particles and the evaporation of moisture is very efficient and intense.

The material to air ratio is limited by an acceptable maximum pressure drop over the system and the prevailing heat transfer for drying.

Features

♦   gas speed superior than   18 - 25 [m/s]   according to the particle size

♦   material to air ratio   < 1,8 [kg/m³]

♦   typical pressure drop   35 - 45 [mbar]   without dust collector

♦   pneumatical transport inceases the specific energy consumption

Ranges of conditions

♦   particles fall down below the terminal velocity

♦   fluidized bed zone (high pressure drop)

♦   critical transition zone with whirling of particles

♦   pneumatic transport for economical operation

Figure 7: Flash Dryer (with disagglomerator)
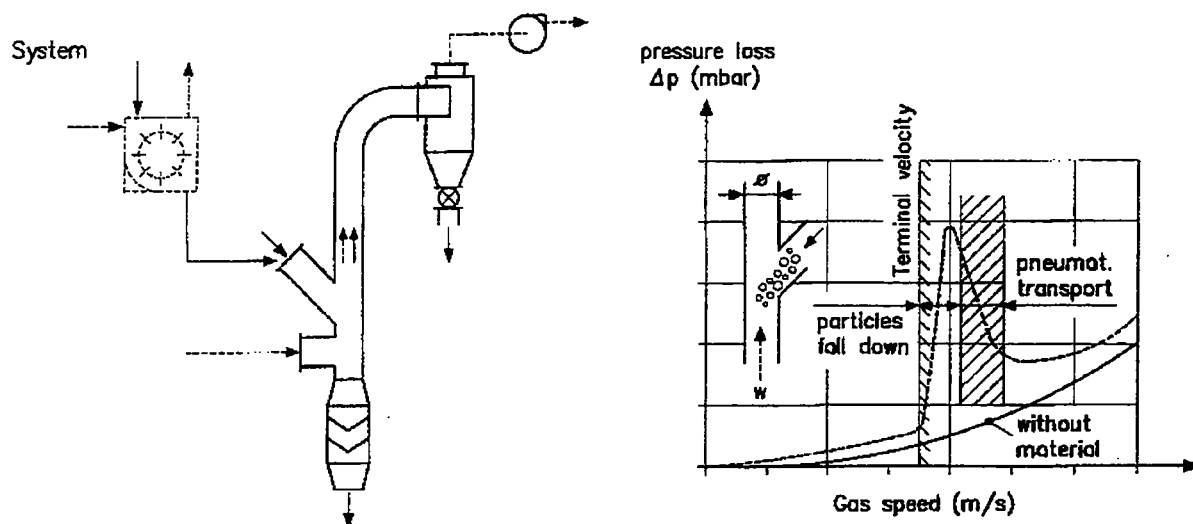
Feed size	(mm)	function of terminal velocity	($\sim$ < 20 mm)
Drying capacity	(%H$_2$O)		< 35
Spec. load	(kg H$_2$O/m^3·h)		< 500
Temperature max.	(°C)		< 900

3.6   Tube mill (without drying compartment)

Design

There are tube mills, mostly two-compartment mills, with end discharge which have no drying compartment. This is normally the case when materials with low moisture content are ground. Often cement mills, producing blended cement with wet additives, have to be adapted to a maximum drying capacity by

♦   utilization of a hot gas source

♦   modification of the inlet arrangement

♦   modification of intermediate diaphragm for maximum open area

♦   modification of mill outlet

♦   provide an appropriate dedusting facility

Drying

The drying must entirely take place in the first compartment. If the material is not sufficiently dry at the intermediate diaphragm

♦   the slot plates may be clogged or

♦   the material does not flow within the 2nd compartment (loss of efficiency and throughput)

Therefore, the maximum moisture content is limited by the drying ability of the 1st compartment. Beyond this limit

♦   a predrying facility must be utilized or

♦   the percentage of the wet component must be reduced or

♦   the mill production must be reduced.

Main heat sources are

♦   hot gases (hot gas generator, kiln or cooler exhaust gases)

♦   grinding heat generated by grinding media

♦   hot clinker (in case of cement grinding)

Features

♦ Max. gas/air speed (over ball charge)	< 2 [m/s]
♦ Max. gas/air speed (inlet, outlet, diaphragms)	< 25 [m/s]
♦ Fan and filter to be adapted to required gas volume and pressure drop	
♦ Filter fabric to be selvted to operate with mois exhaust gas	
♦ Operate filter at min.	30 [°C] above the point

Figure 8: Tube Mill without drying compartment

System

------► hot gas
— → material

Feed size	(mm)	< 30
Drying capacity	(%H$_2$O)	< 5
Spec. load	(kg H$_2$O/m^3· h)	< 150
Temperature max.	(°C)	< 450
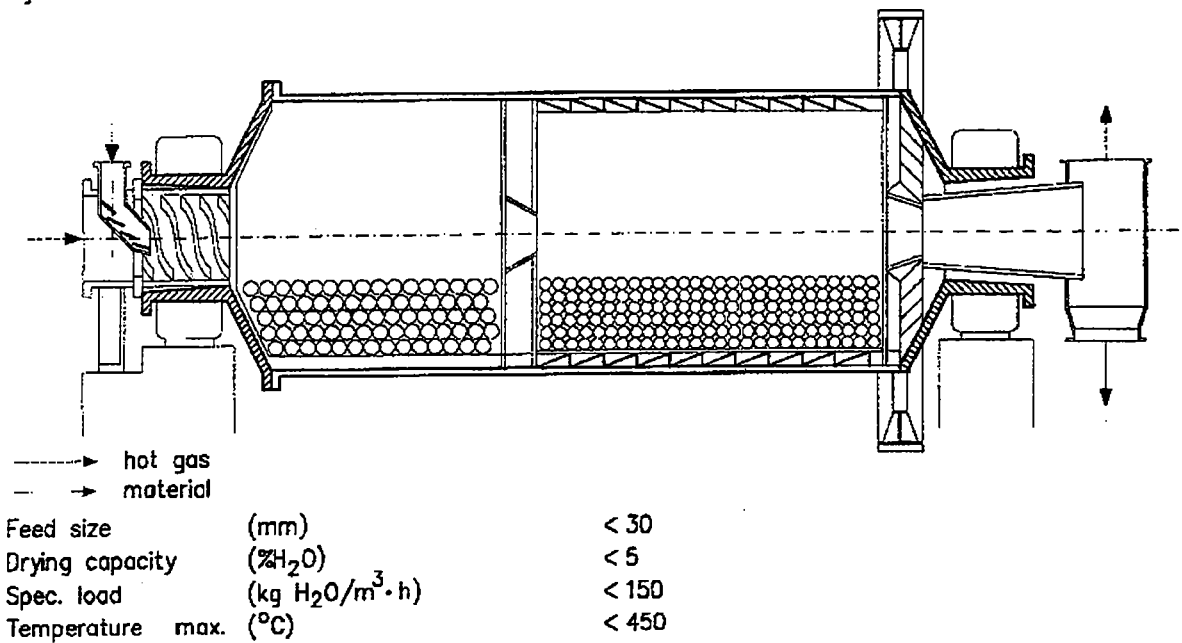
3.7   Tube mills with drying compartment

Design

Typical tube mills for drying/grinding are of a design with

♦ end discharge

♦ center discharge

♦ air swept mills

Drying compartments may be incorporated (normal case) or of overhung type. The overhung compartments are added for a better drying (increase of dryer volume). They allow higher inlet gas temperatures as the mill bearings are placed at the outlet of these compartments.
Drying compartments have to be fitted with lifter plates for dispersion of material in the gas stream. Worn lifters reduce the dispersion effect and the drying efficiency.

Drying

The drying has to take place before the material enters into the grinding compartment. The heat source used is normally hot gas. The drying capacity depends on

♦ total volume of drying compartment(s)

♦ max. acceptable gas speed through mill

♦ hot gas temperatures available/acceptable

♦ type of mill discharge

♦ false air leakage

In case of air swept mills, the gas speed may be higher than in other mills and the gas flow rate to the separator must be adequate for the pneumatic transport of the ground material.

Features

Typical features are very different for all three mill types and are outlined in the paper "Raw grinding systems" VA 93/4013/E.

Figure 9: Tube with drying compartment

System

end discharge

air—swept

center discharge

overhung   integrated

drying compartment
with lifters

		end discharge	air—swept	center—discharge
Feed size	(mm)	25–30	25–30	30–50
Drying capacity	(%H$_2$O)	< 6	< 15	< 15
Spec. load	(kg H$_2$O/m^3·h)		< 200	
Temperature	max. (°C)		< 450	
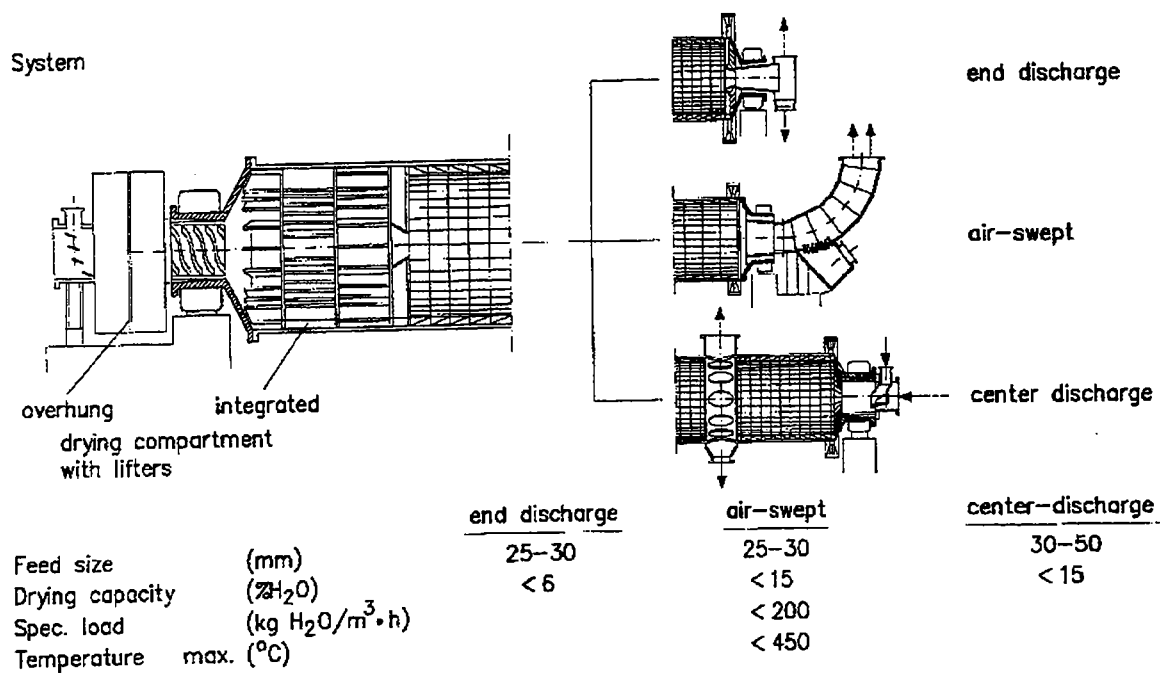
3.8   Vertical roller mills

Design

The vertical roller mill is specially designed for grinding **and** drying.

The mill has to be dimensioned for the required grinding or the drying capacity, whichever is the critical item of the two. The mill table and the mill casing diameter have to be sized for this critical item.

The same applies to the gas flow rate, which has to be adapted either to the grinding needs (internal material circulation ≅ grindability) or to the drying needs.

For very moist and sticky materials, the inlet must be designed to avoid clogging and is preferably centralized (through the separator axis). For coal mills, often screw conveyors force the material to be fed to the grinding table.

Drying

The vertical roller mill is in principle an airswept mill. As the ground material is extracted by the drying gases, an excellent heat exchange between material and gases takes place up to the dust collecting facility.

The hot gases hit the moist material for the first time above the mill's louvre ring. Hot gases enter from the inlet gas channel and the material, first fed to the center of the grinding table, is spread over the nozzles. This first contact is the major drying action, where the gas temperature is already reduced to practically exhaust temperature.

Major material dried and ground in vertical roller mills are:

♦ raw materials

♦ coal

♦ slag

♦ pozzolana

Features

♦ For more technical details see also reports:
   • roller mills, VA 94/4167/E
   • raw grinding systems, VA 93/4013/E

♦ Recirculating gases are needed to ensure a steady gas flow rate through the mill (transport function) in case less hot gases are required for drying

Figure 10: Drying in vertical roller mill

System

2-fan system

3-fan system

- - - - - ► hot gas
———► material

Feed size	(mm)	80–100	(depending on roller diameter)
Drying capacity	(%H$_2$O)	< 20	
Spec. load	(kg H$_2$O/m^3· h)	–	
Temperature max.	(°C)	< 450	
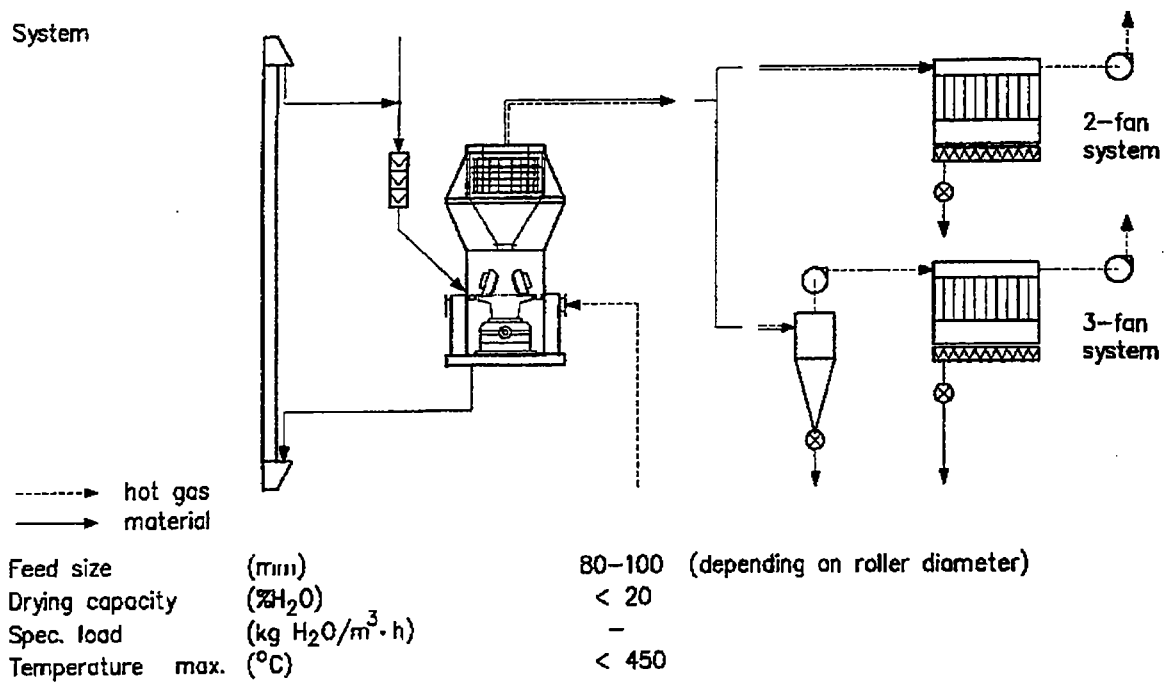
3.9   Separators

Design

Air separators are designed to classify partly fine or already ground particles by means of air.

Certain grinding equipments (e.g. roller press, Horomill) are not suited to dry in the mill and need therefore an additional facility. Up to a certain extent, drying in the separator is possible.

Two problems are obvious:

♦ these mills can handle only materials with low moisture content (efficiency)

♦ only materials with low moisture content can sufficiently be dispersed in the separator.

Drying

The drying capacity in the separator is very limited due to the small volume and the short retention time. This capacity can be increased by adding a flash dryer ahead of the separator to increase the dryer volume.

The maximum permissible hot gas temperature is limited by the lower separator rotor bearing to avoid the overheating of the bearing.

A gas recirculation is needed to keep the gas flow (speed) in flash dryer and separator constant, regardless of drying gases required.

Features

♦ Wet and fine materials can be added after the grinding equipment, preferably to the flash dryer

♦ Partly fine materials can be fed directly to the the separator

Figure 11: Separator (with flash dryer)

System

		without flash dryer	with flash dryer
Feed size	(mm)	< 5	< 5
Drying capacity	(%H$_2$O)	< 5	< 8
Spec. load	(kg H$_2$O/m^3· h)	–	–
Temperature max.	(°C)	< 450	< 900

4. ENERGY BALANCE (HEAT BALANCE)

The calculation or recalculation of a drying process is normally done through an energy balance. The aim of the heat balance is to find the necessary quantity of drying gases to cover the required drying energy.

In principle all energy inputs (indicated as heat) have to be equal to the energy outputs of the drying system.

Procedure:

1) Define borders of the system

2) Define inputs and outputs

3) Compute the balance based on

Heat   inputs = outputs [kJ/kg product]

Gas flow inputs = outputs [Nm³/h]

           (including false air)

4) Observe the restrictions

- max. gas speed
- max. gas temperature (available and equipment related)
- dew points
- plant altitude (➔ air/gas density)

Hints

- The heat is always related to 1 [kg] of system output product dry

- The heat balance is based on a reference temperature of 20 [°C], therefore the Δt is always (t - 20)

- Dust refers to the amount of dust contained in the kiln or cooler exhaust gases/air

- In the grinding heat all major electrical consumers are included (mill, separator, fan) as energy measured at the equipment drive shaft (if not, to be converted with drive efficiency)

- The evaporation heat consists of heating up the water to operating temperature and the subsequent portion of evaporation energy

- The radiation/convection losses are often assumed as a spec. figure related to [kg] water evaporated for simplicity reasons.

Figure 12: Heat Balance

HEAT INPUT

Material
Moisture (water)
Grinding heat
Drying gases
 − kiln exhaust
 − hot gas generator
 − cooler exhaust air
Recirculating gases
Fresh air
False air
Dust (kiln, cooler)

Σ INPUT

Radiation/Convection

HEAT OUTPUT

Material
Evaporation heat
Exhaust gases
Radiation/Convection
Residual Moisture
(Dust)

Σ OUTPUT

 − False air   Radiation/Convection   − Dryer
                                        − Drying/grinding system   − Balance border
                                        − Separator
                                        − etc.

Heat Balance (Example)

Raw grinding system:

Data   Vertical roller mill with filter and fan

Production		145 [t/h]	raw meal dry
Moisture content		9 [%]	initial
Moisture content		0.5 [%]	residual
Electrical energie	mill	1050 [kW]	counter
	separator	35 [kW]	counter
	fan	1100 [kW]	counver
Drive efficiencies		93 [%]	
Drying gases	kiln exhaus gas	340 [°C]	
Mill exhaust gases	(after fan)	90 [°C]	
False air rate	system	12 [%]	
Recirculating air		42 [%]	
Dust in kiln exhaustet gas		70 [g/Nm^3]	

Index

G	[t/h]	Mill production
P_{abs}	[kW]	Absorbed power at counter
η	[-]	Drive efficiency
V	[Nm^3/h]	Gas/air flow rate

Index

k		kiln exhaus
h		hot gas (from auxiliary furnace)
c		cooler exhaust air
f		false air
r		recirculating air
e		mill exhaust gases

cp	[kJ/Nm^3] [kJ/kg]	Spec. heat value (related to preference temperature
W	[kg/h]	Amount of Water

Index

in		moisture in feed material
ev		moisture evaporated
out		moisture in product

q	[kJ/kj H$_2$O]	Evaporation / heat
r	[kJ/kg H$_2$O]	Radiation / convection factor
t	[°C]	Temperature
Δt	[°C]	Temperature difference (operating temp. - reference temp.)
d	[kg/Nm^3]	Dust in drying gas

Figure 13: Heat Balance

Heat Balance	Vertical Roller Mill		Example		"HOLDERBANK"	

INPUT					[kJ/kg]	[%]
Raw material (sensible heat)	G * 1000 *cp * Δt	/(G*1000)	145 * 1000 * 0.83 *(25-20)	/(145* 1000)	4.2	0.9
Grinding heat (mill, separator,fan)	P$_{abs}$ * η * 3600	/(G*1000)	(1050 + 35 + 1100) * 0.93 * 3600	/(145* 1000)	50.4	11.1
Kiln exhaust gases	V$_k$ * cp * Δ t	/(G*1000)	101423 * 1.48 * (340-20)	/(145* 1000)	331.3	72.9
Hot Gases	V$_h$ * cp * Δ t	/(G*1000)		/(145* 1000)		
Cooler exhaust air	V$_c$ * cp * Δ t	/(G*1000)		/(145* 1000)		
Fresh air	V$_l$ * cp * Δ t	/(G*1000)		/(145* 1000)		
False air	V$_{fa}$ * cp * Δ t	/(G*1000)	20984 * 1.30 * (25-20)	/(145* 1000)	0.9	0.2
Recirculating gases	V$_r$ * cp * Δ t	/(G*1000)	73445 * 1.40 * (90-20)	/(145* 1000)	49.6	10.9
Water in feed material	W$_{in}$ * cp * Δ t	/(G*1000)	14338 * 4.19 * (25-20)	/(145* 1000)	2.1	0.5
Dust from kiln gases	V$_k$ * d * cp * Δ t	/(G*1000)	101423 * 0.07 * 1.03 * (340-20)	/(145* 1000)	16.1	3.6
SUM Input					**454.6**	**100.0**

OUTPUT						
Raw meal (sensible heat)	G * 1000 *cp * Δt	/(G*1000)	145 * 1000 * 0.89 *(90-20)	/(145* 1000)	62.3	13.7
Water evaporated	W$_{ev}$ * q	/(G*1000)	13609 * (2501 + (1.88 * 90))	/(145* 1000)	250.6	55.1
Radiation/convection	W$_{ev}$ * r	/(G*1000)	13609 * 50	/(145* 1000)	4.7	1.0
Exhaust Gases	V$_c$ * cp * Δ t	/(G*1000)	195852 * 1.40 * (90-20)	/(145* 1000)	132.4	29.1
Kiln Dust	V$_k$ * d * cp * Δ t	/(G*1000)	101423 * 0.07 * 0.89 * (90-20)	/(145* 1000)	3.1	0.7
Water in Raw meal	W$_{out}$ * cp * Δ t	/(G*1000)	729 * 4.19 * (90-20)	/(145* 1000)	1.5	0.3
SUM Output					**454.6**	**100.0**

Heat of evaporation q = 2501 + (1.88 * t) [kJ/kg H2O]   heat of evaporation at 90 °C   related to :   1 [kg] of raw meal
Radiation/convection factor   r = 50   [kJ/kg H2O]   Temperature 20 [°C]

Figure 14:

cp value of coal

cp value of gases

cp value of solids